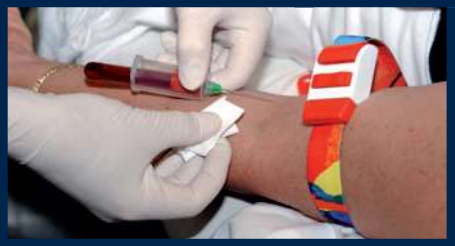
TMT HANDBOOK

Triage, Monitoring and Treatment of people exposed to ionising radiation following a malevolent act



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Photos front page, clockwise from top left: NRPA, NRPA, NRPA, REAC/TS, WHO and STUK.

Figure A8.5. An example of a beta dose rate monitor. Photo: HPA.

Gas-filled detectors are suitable for the detection of alpha emitters, if the window material is made of light elements, typically beryllium (25 - 50 µm). With this device, soft gamma rays and X-rays (< 30 keV) may also be detected.

Figure A8.6. Examples of alpha contamination monitors. Photos: HPA.

Figure A8.7. An example of beta and X-ray contamination monitor. Photo: HPA.

Figure A8.8. An example of alpha, beta and gamma contamination monitor. Photo: STUK.

Neutron counting

Nuclear materials typically emit alpha particles, photons, X-rays and neutrons. The neutron radiation is a very characteristic feature of nuclear materials, such as plutonium, and it is difficult to shield. Neutron detection is therefore an efficient way to monitor the presence of nuclear materials. However, neutron detection is more difficult than gamma detection.

Neutrons are detected as a result of the nuclear reaction of a neutron with a nucleus resulting in detectable charged particles. The most common neutron detector is a pressurised ^{3}He filled tube. Other widely used compounds are $^{10}BF_3$, ^{6}Li and ^{10}B. $^{10}BF_3$ is gaseous and is used in proportional counters. Solid state detectors are either scintillation material or semiconductors that are doped with boron or lithium. The disintegration of lithium or boron produces charged particles that further produce scintillations.

The scintillation materials may be sensitive to gamma radiation, which has to be discriminated from the neutron pulses. The separation of neutron and gamma events in a gamma sensitive neutron detector is performed either by pulse height discrimination or pulse shape discrimination. Table A8.1 contains a summary of neutron detection materials and their main characteristics.

Table A8.1. Neutron detection materials and their properties. Efficiency is defined as percentage of detected neutrons/neutron fluence. Detectors based on gamma sensitive materials require a mean to discriminate between gamma and neutron pulses.

Material	Efficiency	Gamma sensitivity	Type
BF_3 gas	<10 %	yes	high pressure tube
^3He gas	~30 %	yes	high pressure tube
LiI	25-30 % (~100 % for enriched ^6Li)	yes	scintillator
Li in ZnS(Ag)	60 %	low	scintillator
Li doped glass	80 %	low	scintillator
B_4C	50-80 % (thin layer)	low	semiconductor
Si Pin diode Cd foil	<10 %	yes	semiconductor

Portable detectors are mainly based on proportional counters. The advantage of the gas-filled tube is the simplicity of the readout electronics and the discrimination is fairly easy to implement.

Figure A8.9. Example of a hand held monitor for measuring neutron dose rate. Photo: HPA.

Nuclide identification using gamma spectroscopy

Most radioactive substances produce gamma rays of various energies and intensities. A detailed analysis of a collected gamma spectrum is typically used to determine the identity and quantity of gamma emitters present in the source. The equipment used in gamma spectroscopy includes an energy sensitive radiation detector, amplifiers, multichannel analyser and data readout devices. Gamma spectroscopy systems are selected to take advantage of several performance characteristics. Two important characteristics are resolution and efficiency. The most common detectors include sodium iodide (NaI) scintillation counters and semiconductor detectors, e.g. high purity germanium detectors (HPGe).

Scintillation detectors use crystals that emit light when gamma rays interact with the atoms in the crystals. The intensity of the light produced is proportional to the energy deposited in the crystal by the gamma ray. The detectors are joined to photomultipliers that convert the light into electrons and then amplify the electrical signal provided by those electrons. Common scintillators include thallium-doped sodium iodide, NaI(Tl), or caesium iodide, CsI(Tl), detectors. Because of the poor resolution of NaI and CsI based detectors, they are not suitable for the identification of complicated mixtures of gamma ray producing materials. Scenarios requiring such analyses require detectors with higher resolution, like HPGe.

Semiconductor detectors, also called solid state detectors, are fundamentally different from scintillation detectors. They use a semiconductor to detect traversing charged particles or the absorption of photons. In these detectors, radiation is measured by means of the number of charge carriers set free in the detector, which is arranged between two electrodes. Common semiconductor based detectors include germanium, cadmium zinc telluride (CZT) and lanthanium bromide ($LaBr_3$). High purity germanium (HPGe) detectors produce the highest resolution commonly available today, which makes them optimal for nuclide identification. A draw back of these detectors is that cryogenic temperatures are vital to the operation.

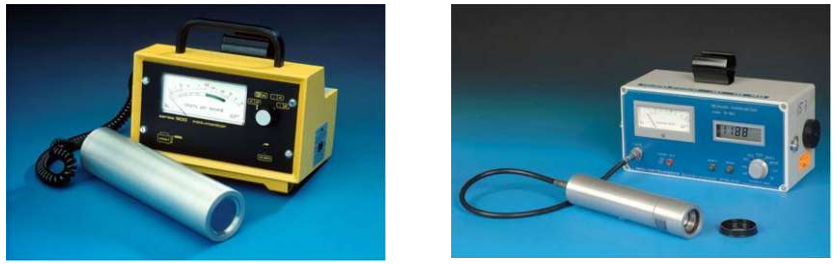

Figure A8.10. Examples of NaI(Tl) detector based monitors used as gamma contamination monitors. Photos: HPA.

Figure A8.11. Example of portable gamma spectrometry equipment. Photo: STUK.

Figure A8.12. Examples of Radionuclide Identification Devices. All are gamma spectrometers with a neutron monitoring option. Photos: STUK.

Figure A8.13. An example of a radiation surveillance vehicle and mobile laboratory. The laboratory is equipped for dose rate monitoring, nuclide identification, aerosol sampling, sample and in situ gamma spectroscopy measurements and alpha spectroscopy measurements, as well as operational voice and data communication. Photo: STUK.

Wipe tests

Wipe tests are used both for determination of environmental surface contamination [Instructions E.18 and Information E.18:2e] and for skin contamination. The wipe test measures only the contamination that can be removed from the surface. For determination of surface contamination a filter paper may be used to wipe the surface. Wipe approximately an area 10 cm x 10 cm with the dry or moistenned filter paper. A background sample is also needed. Frequently, the amount of activity removed fram a surface by a wipe, is assumed to be 10 %. This is known as the removal factor. If the measurement result of a sample is three to four times higher than the background, it can be concluded that contamination is present.

The contamination monitoring equipment used depends on the type and energy of the ionising radiation. In general, for beta emitters a GM counter can be used, while for gamma emitters a scintillation counter or a gamma spectrometer can be used.

The ISO 7503-1 standard gives a description of the calibration procedure and sampling for surface contamination measurements. The surface contamination is measured in Bq/cm^2. It is proportional to the net counting rate and a calibration factor. The calibration factor is a function of the instrument's efficiency for the specified radionuclide, the area wiped, the source efficiency and the removal factor.

Internal contamination

Whole body measurement with specially designed whole body counters

Whole body counting with special equipment can only be done in dedicated laboratories (fixed or transportable). Such measurements are time consuming and not always suitable for rapid measurements of large groups of people. No instructions for this type of measurements will be given in the Handbook. For such measurements, contact experts that will give their advice on where the whole body counting measurements and the dose assessments can be made.

Several commercial systems exist for the rapid monitoring of the whole body in a routine, radiological protection context. These may consist of a

booth in which the subject stands upright in front of, or possibly between, arrays of stationary detectors. In other designs, a single detector (HPGe or large NaI(Tl)) may perform a scan of the body, with the possibility of delivering crude indications of how any internal contamination is distributed. If installed software is employed to produce estimates of body content based on a built-in library of calibration spectra, the validity of the calibration needs to be assessed in relation to the particular conditions of measurement.

Some organisations have monitors installed in vehicles for regular monitoring of workers. These monitors could conveniently be brought into service.

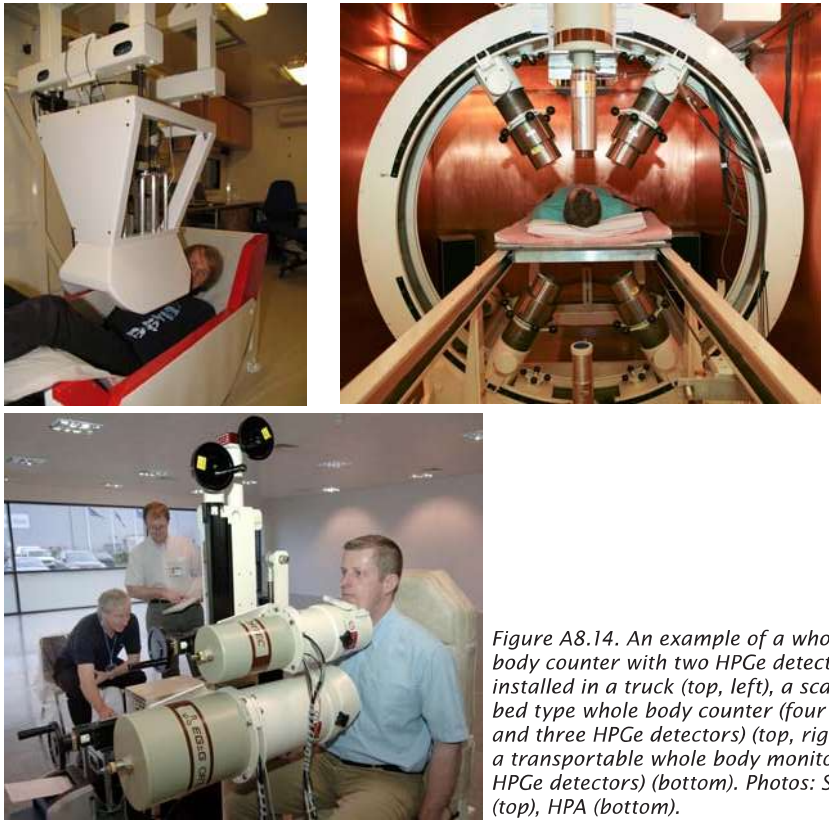

Figure A8.14. An example of a whole body counter with two HPGe detectors installed in a truck (top, left), a scanning bed type whole body counter (four NaI(Tl) and three HPGe detectors) (top, right) and a transportable whole body monitor (two HPGe detectors) (bottom). Photos: STUK (top), HPA (bottom).

Improvised *in vivo* monitoring arrangements

As an alternative to importing dedicated or established facilities, arrangements may be improvised, making use of any suitable scintillation counter (including possibly a gamma camera with collimator removed) or large semi-conductor (germanium etc.) detector. These arrangements can be made sufficiently flexible to allow:

- For adjustment of detector and subject position in optimising count rate and accuracy; and
- For collimators to be fitted where activity must be assessed in specific organs.

Various geometries exist for assessment of whole body contamination. They include:

- Arc geometry: the subject reclines on a curved bed so that all parts of the body are roughly equidistant from a detector located at 1-2 metres distance;
- Simple arrangements, in which the subject stands or lies with the abdomen located on the axis of the detector at a 1 metre (or greater) distance; and
- Chair geometry: the subject is seated with the detector located at (typically) 0.4 m distance from the trunk and thighs.

The approach adopted will be influenced by several factors including the detectors available, the anticipated distribution of radionuclides in the body, the possible need to accommodate sick or injured people, and the availability of appropriate shielding. At the lower end of the activity range under consideration (10^4-10^7 Bq), partial shielding would be required to achieve adequate statistical reliability in a short counting time. Local shielding of the detector, to the extent possible without impairing its sensitivity to activity in the subject, may be considered. Shielding of the subject, on all sides except the one exposed to the detector, is recommended. In the absence of such shielding, the subject's presence may modify the ambient radiation field, and it may be important to reproduce the relevant conditions when recording the background response. Precautions will include the provision of an appropriate inactive phantom in place of the subject. As a guide to the thickness of such shielding, the aim should be for 50 mm of lead or its equivalent in some other material

such as steel. In practice, weight limitations may dictate less effective shielding. The frequency of background checks should be chosen taking into account the importance of early detection of surface contamination brought into the shielded region, or of variations in the local background arising from meteorological changes.

If it is necessary to assess the activity of radionuclides in specific organs or regions of the body, the detector used for whole body monitoring may be fitted with a suitable collimator. In the specific case of monitoring the thyroid for radioiodine, it is best to use a small detector, preferably collimated. Suitable materials should be used to shield parts of the body that may have irremovable surface contamination, to avoid erroneous assessments of internal contamination. If the affected areas are so extensive that this approach is inapplicable, excretion analysis will be required to provide a basis for the assessment of committed effective dose.

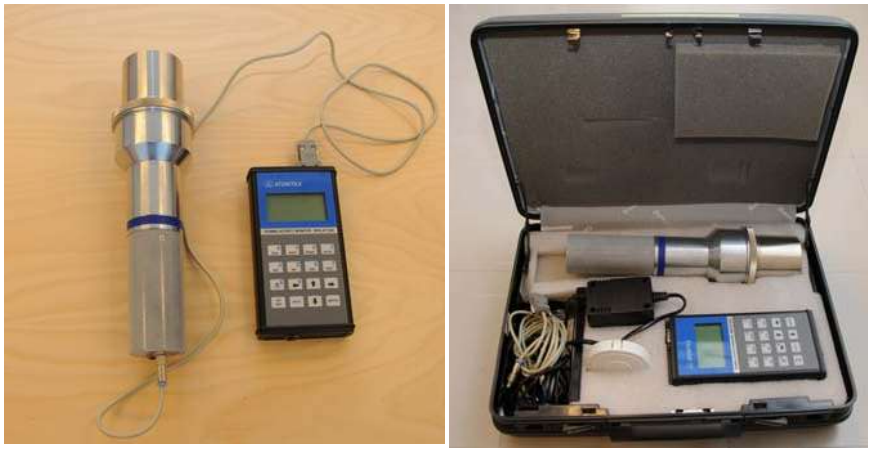

Figure A8.15. Examples of simple NaI(Tl) gamma spectrometric equipment for whole body and thyroid measurements. Photos: STUK.

The accuracy of measurements

The continued validity of an adopted calibration should be confirmed daily, through measurements of a designated reference point source in a fixed and reproducible geometry. As further confirmation, there should, in addition, be occasional re-measurements of the response to a phantom containing a known quanitity of a single radionuclide. Results with an estimated accuracy of a factor of 2 or better, are often adequate. There may later be a

case for more rigorous assessment of internal contamination and ensuing exposure in a representative subgroup of those monitored with simple systems.

Some examples of instruments and calibration factors for whole body measurements of ^{137}Cs and measurements of ^{131}I in the thyroid are given in Tables A8.2-A8.5. The calibration factors for the instruments available need to be determined in advance by the local monitoring specialists.

Measurement of ^{137}Cs with gamma cameras

Gamma cameras at hospitals can be used for contamination monitoring when large groups of people need to be measured in emergency situations or when no other whole body counting equipment is available. An advantage is the trained personnel with experience from such measurements. If the camera is used without collimator and placed close to the body of the person to be measured, care should be taken to arrange for mechanical stability of the configuration. The background variations in certain emergency situations and the shielding effect of other persons close to the camera cause the highest uncertainties.

Table A8.2. Calibration of hand held instruments for measurements of ^{137}Cs in humans for two different measurement geometries. The activity is calculated by dividing the background substracted measurement value by the calibration factor. Detector in contact with the body (Rahola et al, 2006).

Manufacture	Type	Type of detector	Detector size	Measurement geometry	Calibration factor[1]
BICRON	ANALYST	NaI(Tl)	50 × 50 mm	Back	$2.5x10^{-3}$
BICRON	ANALYST	NaI(Tl)	50 × 50 mm	Palmer (lap)	$3.9x10^{-3}$
SAPHYMO-STEL	SPP2	NaI(Tl)	25 × 50 mm	Palmer (lap)	$7.9x10^{-4}$
RADOS	SRV-2000	GM detector		Palmer (lap)	$6x10^{-7}$
Exploranium	Gr-110s	NaI(Tl)	38 × 38 × 50 mm	Palmer (lap)	$1x10^{-3}$
Exploranium	Gr-110s	NaI(Tl)	38 × 38 × 50 mm	Back	$1.1x10^{-3}$
RNI	10	GM detector		Palmer (lap)	$1.3x10^{-6}$
RNI	10	GM detector		Back	$6.3x10^{-7}$
Morgan	Minimonitor 900	NaI(Tl)	25 × 19 mm	Back	$9.5x10^{-5}$
Morgan	Minimonitor 900	NaI(Tl)	2,5 × 32 mm	Back	$3.8x10^{-4}$
Morgan	Minimonitor 900	NaI(Tl)	25 × 19 mm	Palmer (lap)	$9.5x10^{-5}$
Morgan	Minimonitor 900	NaI(Tl)	2,5 × 32 mm	Palmer (lap)	$3.8x10^{-4}$
Made in Russia	SRP-88	NaI(Tl)	25 × 40 mm	Back	$5.7x10^{-5}$
Made in Russia	SRP-88	NaI(Tl)	25 × 40 mm	Palmer (lap)	$1x10^{-4}$

Notes:
1 The calibration factor is given as microsievert/Bq for the scintilation detectors and in cps/Bq for the Geiger-Muller detectors.

Table A8.3. Calibration of hand held instruments for measuring ^{131}I in the thyroid. The instrument placed close to neck (Rahola et al, 2006).

Manufacture	Type	Detectortype	Detector size	Calibration factor[1]
BICRON	ANALYST	NaI(Tl)	50 × 50 mm	0.041
SAPHYMO-STEL	SPP2	NaI(Tl)	25 × 50 mm	0.012
Exploranium	Gr-110s	NaI(Tl)	38 × 38 × 50 mm	0.021
Mini Instruments	6-90 Scaler ratemeter	NaI(Tl)	25 mm	0.0045
RNI	10	GM		0.000016
SAPHYMO-Phy	ADB/AD-6	Plastscint.	76 × 76 mm	0.013
SAPHYMO-Phy	ADB/AD-3R	GM		0.000013
Automess	AD-b/AD-6	Plastscint.	76 × 76 mm	0.013
Automess	6150 AD3 R	GM	18 × 8 mm	0.000013
Made in Russia	SRP-88	NaI(Tl)	25 × 40 mm	0.0012
Morgan	Minimonitor 900	NaI(Tl)	25 × 19 mm	0.0042
Morgan	Minimonitor 900	NaI(Tl)	25 × 32 mm	0.0093

Notes:
1. The calibration factor is given as microsievert/Bq for the scintilation detectors and in cps/Bq for the Geiger-Muller detectors.

Table A8.4. MDA and sensitivity for measurement of ^{137}Cs and ^{131}I with gamma camera in different configurations (choice of collimator and detector height). Before the activity calculation, the background has been subtracted (Wallström et al, 1999).

Energy interval (keV)	Collimator	Phantom size (kg)	MDA ^{137}Cs in whole body (kBq)		MDA ^{131}I in thyroid (kBq)		Sensitivity ^{137}Cs in whole body, centered (cps/kBq)		Sensitivity ^{131}I in thyroid, neck (cps/kBq)	
			5 cm	35 cm	10 cm	40 cm	5 cm	35 cm	10 cm	40 cm
50-450	None	14	0.25	0.90			78	24		
		61	0.40	1.0	0.10	0.45	46	21	170	47
		93	0.45	1.1			39	18		
	LEGP	14	0.80	2.3			9.1	3.3		
		61	2.1	3.5	0.80	2.5	3.8	2.2	9.8	3.4
		93	2.3	4.2			3.0	1.7		
	HEGP	14	3.6	8.5						
		61	12		13	17				
		93	11	17						
550-750	None	14	0.30	1.3			12	3.2		
		61	0.70	2.0	1.5	9.0	5.4	2.2	2.6	0.47
		93	1.6	3.2			2.2	1.2		
	LEGP	14	1.1	2.9			2.9	1.1		
		61	2.5	4.9	4.5	20	1.2	0.64	0.67	0.16
		93	3.0	5.8			0.93	0.52		
	HEGP	14	7.0	17						
		61	13	31	26	47				
		93	11	27						

Table A8.5. Technical characteristics of detectors used in assessing internal radioactive contamination in the local population following the reactor accident at Chernobyl. Table adapted from IAEA TECDOC 746,1994.

Unit type	Mass [kg]	Detector size (diameter, thickness, mm)	Shielding	Measurement geometry	Signal processing	Throughput measurements/ hour	MDA, kBq	Application
NC25, "gamma thyroid radiometer"	120	40, 40	lead collimator	150-200 mm from neck	SCA, digital output analogue	100	1	^{131}I in thyroid
SRP-68-01, gamma dosemeter	6	20, 20	none	close to neck close to abdomen	rate meter [wide energy band]	60	6 2	^{131}I in thyroid whole body ^{137}Cs + ^{134}Cs
OMEGA800, medical gamma camera without collimator	600	500, 8	none	450 mm above supine thorax	SCA	35	4	whole body ^{137}Cs + ^{134}Cs
QBM-1A, "quick body monitor"	200	0.3 m^2	partial 8-10 mm Pb	chair	SCA	60	0.5	whole body ^{137}Cs + ^{134}Cs
WBC25, transportable whole body counter	450	75, 75	partial, 20-50 mm Pb	chair	MCA	36	1	whole body ^{137}Cs + ^{134}Cs
WBC22, established whole body counter	3500	203, 102	totally enclosed 150 mm steel	chair	MCA	10	0.04	whole body ^{137}Cs + ^{134}Cs